

LHCb commissioning and readiness for first data

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Abstract. LHCb has been installed by spring 2008, followed by intensive testing and commissioning of the system in order to be ready for first data taking. Despite the horizontal geometry of the LHCb detector it was possible to collect over one million useful cosmic events that allowed a first time alignment of the sub-detectors. Moreover events from beam dumps during the LHC synchronisation tests provided very useful data for further time and spacial alignment of the detector. Here we present an overview of our commissioning activities, the current status and an outlook on the startup in 2009.

1. Introduction

The LHCb detector [1] at the Large Hadron Collider is dedicated to study the physics in the decay of b-flavoured and other heavy hadrons. At the nominal luminosity of $2 \times 10^{32} \text{cm}^{-2} \text{s}^{-1}$ at the location of LHCb and a production cross section of $\approx 500 \mu\text{b}$ at 14 TeV proton-proton collisions, $10^{12} \text{b}\bar{\text{b}}$ pairs are expected to be produced annually. The modest luminosity requirement for LHCb can be met very early during LHC operation, long before the high luminosity runs and later maintained adjusting the LHC optics when larger luminosities are delivered to the other multi-purpose experiments at the LHC.

2. Detector Overview

LHCb is designed as a single arm forward spectrometer adapted to the angular distribution of the $\text{b}\bar{\text{b}}$ pairs which are produced predominantly at low polar angles as shown in Figure 1. The detector covers an angular region from about 10 mrad to 300 (250) mrad in the bending (non-bending) plane of the magnet. LHCb uses a warm dipole magnet that delivers an integrated magnetic field of 4 Tm. There are two Ring Imaging Cherenkov detectors, RICH1 and RICH2 located before and behind the magnet, respectively. These two detectors that use three different radiator materials, aerogel, C_4F_{10} and CF_4 , give excellent π -K separation in a large momentum range of 2-100 GeV/c. The vertex detector (VELO) and the full silicon tracking station (TT-station) before the magnet and the three tracking stations behind the magnet provide the tracking system of LHCb. The stations behind the magnet are divided into the silicon strip Inner Tracker and the straw tube Outer Tracker. The calorimeter system consists of a Scintillator Pad Detector and Preshower (SPD/PS), a “shashlik type” electromagnetic calorimeter, and the Fe plus scintillating tile hadronic calorimeter. The detector is completed with a muon system that uses multi-wire proportional chambers and triple-GEM’s in the very first muon station.

LHCb is using a level-0 hardware trigger that reduces the initial interaction rate of 16 MHz down to 1 MHz using transverse energy measured in the calorimeters and the two highest P_T muons seen in the muon chambers. After a level-0 trigger, the whole detector is read out and

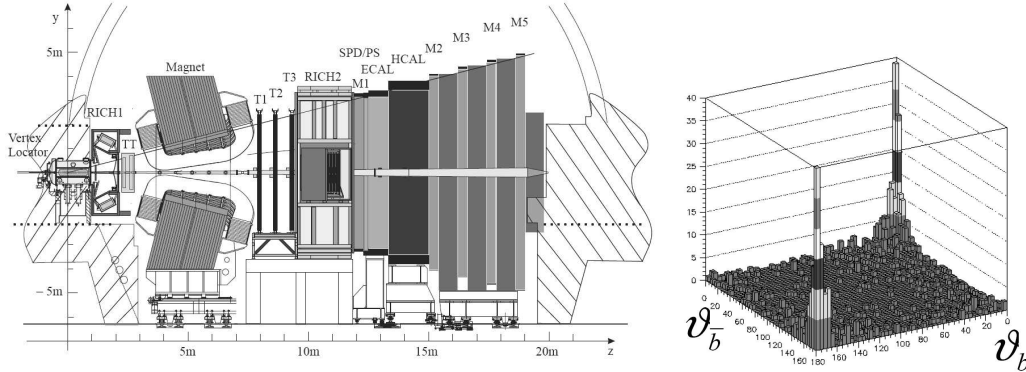


Figure 1. Left: Overview over the LHCb detector. Right: the expected angular distribution of $b\bar{b}$ pairs produced at LHC.

the information used in the high level trigger (HLT) where in several stages of reconstructing the events, the rate is reduced to 2 kHz at which the events are stored.

3. Commissioning

Commissioning activities have started in 2007 with the first individual sub systems and safety devices being tested in parallel with the final installation of subdetectors which finished in spring 2008. First commissioning activity made use of internal test pulses to test the functionality of the readout and of detector elements. Sending test pulses and receiving the detector responses allows testing the full control and readout chain of the sub-detectors. Dead or noisy channels are located (and eventually fixed/replaced where possible) and consistency checks also allow in certain cases to track down possible cabling swapping and alike. From known cable lengths and delays measured using test pulses the initial settings for the time alignment were set for the different sub-detectors.

3.1. Commissioning With Cosmic Events

Despite the horizontal geometry of the LHCb detector and a very low rate under 1 Hz of reasonably horizontal cosmic particles within the 250 mrad of the horizontal acceptance, over a million cosmic events were recorded in LHCb. First these rare cosmic events were used to commission the level-0 trigger, aligning calorimeters and later the muon chambers in time to one another as done end of 2007. Special low thresholds were used in the calorimeter to be able to trigger on MIPs together with a loose coincidence between ECAL and HCAL which in the end results in a trigger rate of about 10 Hz. A cosmic particle showing a nice “track” in the calorimeters is shown in Figure 2. Internal time alignment of the various calorimeter cells using the known pulse-shape from test-beam measurements is reaching a precision of about 3 ns. The muon trigger also was used for cosmic events using a coincidence between two stations omitting the vertex constrained used in the real experiment’s trigger. The muon stations were also time aligned using these cosmic events as shown in the left part of Figure 2. Time alignment with cosmic muons in LHCb needs to disentangle the forward from the backward going particles. Which is nicely displayed in Figure 2, showing the timing for forward and backward particles.

The Outer Tracker and Inner Tracker stations located in front of the calorimeter stations (separated only by the RICH2 detector) were commissioned using the cosmic particles triggered by either the calorimeters or the muon detector. Despite the small surface of the Inner Tracker, some clear cosmic events could be seen as “coincidences” of hits in neighbouring silicon layers

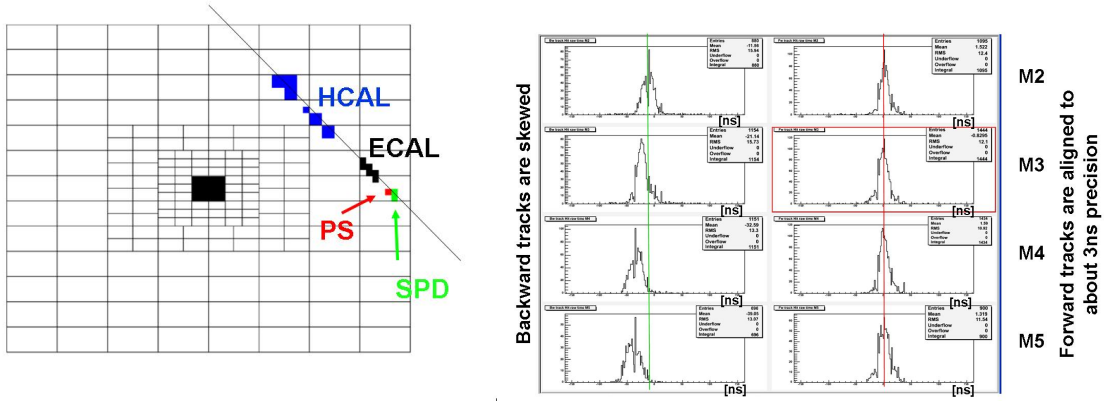


Figure 2. Left: a cosmic event in LHCb as seen by the calorimeters. Right: time alignment of the muon chambers with cosmic particles. One can see that a time alignment with a precision of about 3 ns is achieved for particles that cross the detector in the proper direction, while for backward going particles the signal arriving times are skewed.

within a detector box. This allowed for a very first rough time alignment of the Inner Tracker with the calorimeters, using known cable lengths for the internal time alignment. Very helpful for this exercise was the possibility in LHCb to trigger on and read out up to 15 consecutive events. This allowed to read out a window of ± 7 events around an event triggered by the calorimeters and find the corresponding coincidences in the Inner Tracker. Two tracks with hits in all three Inner Tracker stations were found in over a million cosmic triggers.

3.2. Commissioning With Beam Events

While commissioning with cosmic events is not feasible for the vertex detector and the TT-station “far away” from the calorimeters, we profited here from synchronisation tests in the injection lines done by the LHC machine group. During these tests, the injection beam of the SPS accelerator was dumped on a beam stopper (TED) located about 300m downstream of LHCb. This resulted in a large number of about 10 GeV muons in LHCb and the first tracks seen in the VELO. Careful analysis of these data allowed also for first spatial alignment studies of the VELO, and some of those results are shown in Figure 3. It shows the hit residuals as a function of the strip pitch which increases with radius of the radial strips. The plot shows the performance achieved during the test-beam measurements and the expected performance for binary resolution without any charge sharing between the strips. The current measured resolution after this first alignment step was already well inbetween these two lines.

The TT-station consists of only four individual layers, too little to make stand alone tracking. However, once can extrapolate the VELO tracks and look at the hit residuals in the different layers of the TT-station. This results in very nice peaks with a widths of about $500 \mu\text{m}$ and small overall shifts of the order of some hundred μm depending on the layer. For one layer this is shown in figure 3. The spread expected from simple extrapolation of the tracks would be of the order of $300 \mu\text{m}$ due to the resolution in the VELO. This shows a very good initial alignment of the two sub-detectors w.r.t each other as well as a first hint of the internal positioning accuracy of the TT-station modules.

The large number of hits recorded in the silicon trackers during these “TED-events” also allowed for a very accurate time alignment of the detectors within a few ns, not achievable with the very limited number of cosmic events. A reconstructed charge distribution in the Inner

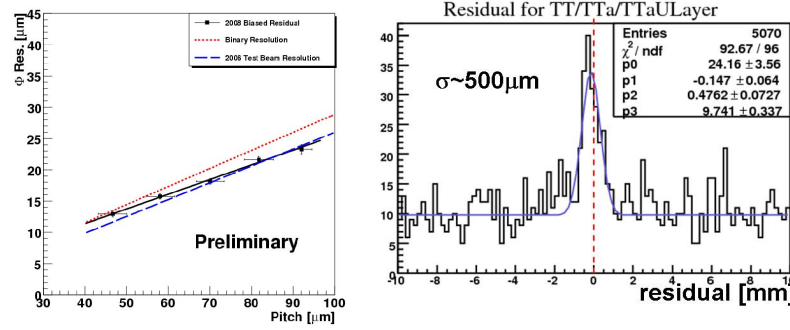


Figure 3. Spatial alignment using beam dump events. The right plot shows the resolution in Φ of the VELO as a function of the strip pitch which changes with sensor position. The left plot shows the residual of tracks reconstructed in the VELO and extrapolated to one of the TT-station layers.

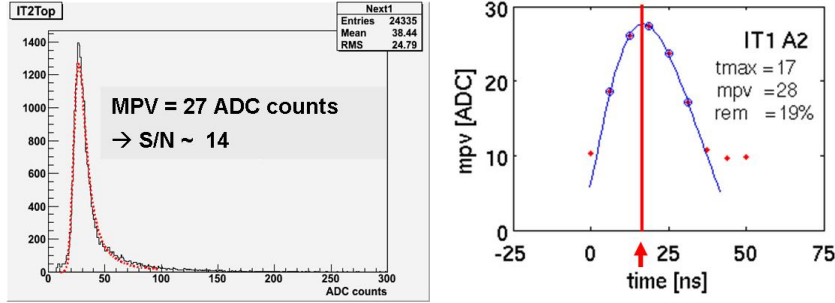


Figure 4. Time alignment of the Silicon Trackers using beam dump events. The left plot shows a Landau distribution from the deposited charge in ADC counts and the right plot shows the reconstructed pulseshape.

Tracker and a pulseshape derived from varying the relative timing between the beam and the readout clock is shown in Figure 4.

4. Conclusions

Commissioning in LHCb had started as early as 2007. making extensive use of internal generated test pulses but also cosmic ray events despite the horizontal geometry of LHCb. Very useful proved the beam induced events when the injection beam was dumped in the injection line some 300m behind the detector which in the end allowed us to get first time alignment and spatial alignment of basically all sub-detectors. The long shutdown that followed after the LHC incident on September 19 is being used for maintenance and further improvement on the overall efficiency of the detector. The time is also being used for more tests of the detector readout at the full trigger rate of 1 MHz, data processing and writing. The latter has been successfully tested to speeds up to 1.9 kHz, close to the design of 2 kHz. For the year 2009 run, the full HLT computer farm will be available which will allow to take data at full LHCb rate.

[1] The LHCb Collaboration, Journal of Instrumentation 3 (2008) S08005.